NUTRIENT MANAGEMENT SUPPORT SYSTEM (NuMaSS), Version 2.0
SOFTWARE INSTALLATION AND USER'S GUIDE

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D.L. Osmond[1], T. Jot Smyth[1], R.S. Yost[2], W.S. Reid[3], D.L. Hoag[4], W. Branch[5],
X. Wang[2], and H. Li[2]

[1]Soil Science Department, Box 7619, North Carolina State University, Raleigh, NC 27695
[2] Department of Agronomy and Soil Science, 1910 East West Rd., University of Hawaii at Monoa, Honolulu, HI 96822
[3]Soil and Crop Sciences Department, 803 Bradfield Hall, Cornell University, Ithaca, NY 14853
[4]Department of Agriculture & Resource Economics, B328 Andrew G. Clark, Colorado State University, Ft. Collins, CO 80523
[5]Understanding Systems, Inc., 1005 Capability Dr., Raleigh, NC 27606

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Personnel Involved In The Development Of NuMass

I. Program Integration - Deanna L. Osmond (NC State University), Jot Smyth (NC State University), W. Shaw Reid (Cornell University), Russ Yost (University of Hawaii), Will Branch (Understanding Systems), Xinmin Wang (University of Hawaii) and Hu Li (University of Hawaii)

II. Data Base Development - Deanna L. Osmond (NC State University), Russ Yost (University of Hawaii), Pedro Luna (NC State University), Steve Pratt (Understanding Systems) and Will Branch (Understanding Systems)

III. Acidity Module - Jot Smyth (NC State University), Russ Yost (University of Hawaii), Anthony Juo (Texas A&M University), Eugene Kamprath (NC State University) and Will Branch (Understanding Systems).

IV. Nitrogen Module - W. Shaw Reid (Cornell University), Deanna L. Osmond (NC State University), Jot Smyth (NC State University), Pedro Luna (NC State University), Dan Israel (NC State University) and Will Branch (Understanding Systems)

V. Phosphorus Module - Russ Yost (University of Hawaii), Xinmin Wang (University of Hawaii), Hu Li (University of Hawaii) and Fred Cox (NC State University)

VI. Economics Section – Dana Hoag (Colorado State University), Deanna Osmond (NC State University), Jot Smyth (NC State University), Russ Yost (University of Hawaii) and Shaw Reid (Cornell University)

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GETTING STARTED

Computer Settings

Before you load the Nutrient Management Support System (NuMaSS), you MUST check that your <u>font size</u> setting in Windows is on <u>small</u>, otherwise the <u>program will not display properly</u>. The checking is done, by clicking on your "Control Panel", then click on "Display" and finally on the "Settings" tab. Then click on the "Advanced" button in the lower right portion of the window.

Loading NuMaSS

The NuMaSS software is stored on a CD-ROM and must be installed onto the computer before it will run. Insert the CD into the CD-ROM drive and display the contents of the CD-ROM using Explorer.

Change directories on the CD to: "NuMaSS_Install". In this directory, you will see a executable program named "Setup" (or "Setup.exe"). Double click on the setup program to start the installation. During the installation you will be asked two questions. The first question is where to install the program files for NuMaSS. This is the directory where all the program files and database files will be stored. You can either select the default directory ("C:\Program Files\USI\NuMaSS ") or click on the browse button in order to select the directory you want. Map data for NuMaSS will always be installed in the following directory: "C:\Program Files\USI\NuMaSS\world_maps". The second question that you will be asked during the install is what you want the NuMaSS shortcut directory to be named in your Start menu Programs group. The default name is "NuMaSS".

After NuMaSS is loaded onto your computer, the install program will give you the opportunity to run the program. To start the program at this time, simply check the "launch" box that is found at the end of the installation program and the software will run. Otherwise, the program will terminate.

Starting NuMaSS After the Initial Installation

1) Using the Windows Start menu find the location that you indicated that you wanted the program shortcut to be installed in the Programs group.

2) Click on the NuMaSS shortcut icon.

Running NuMaSS
The program is composed by five sections: *Geography*, *Diagnosis*, *Prediction*, *Economics* and *Results*. *Geography*, *Diagnosis*, *Prediction*, and *Economics* constitute the backbone of this program that gathers and collates information from the user; and *Results* displays the results of the processed information.

With the exception of a few variables, NuMaSS 2.0 runs whether the information required is fully provided or not. However, it is highly advisable to enter as much information as possible. Otherwise you may not get the expected results. If you should enter a value that is outside the possible range for any given parameter, a notification box will pop-up. The box reads, "Your entered value is (above / below) the acceptable limit of X." Close the notification box and either change the value to within the range identified or continue.

To Save Your NuMaSS Values:
1) Click on File from the main menu
2) Click on "Save Current Values..." in the File sub-menu

A Save As dialogue window will appear and ask you to save your file. You may save your files anywhere on your system, but the file names must end in ".num". Also, there is no limit to the number of files you can save.

To Open a NuMaSS Values File (*.num):
1) Click on File from the main menu
2) Click on "Open Previous Values..."
An Open dialogue window will appear and ask you to select a file to open.

When you open a NuMaSS Values File, the program will take a few seconds to populate the interface with the values from the file. You may also see a popup message regarding the depth of incorporation, just click OK to proceed with loading the values.

NOTE: You may save and load values at anytime. However, if you load a set of values from a file after having already entered values, all of the values you entered manually will be over-written.

WARNING: Although the .num files are text files, it is not advisable for the user to edit these files manually in a word processor or text file editor. These files (.num) are in a specific format, and if this format is not maintained, you could render the file unusable.

In addition, the values files (*.num files) cannot be shared between users with different decimal / comma separator settings. For example, if you are using "English (US)" as the regional setting, you cannot load a .num file created by a user whose regional setting is "Portuguese (Brazilian)".

NUTRIENT MANAGEMENT SUPPORT SYSTEM (NuMaSS)

Project Summary

Soil acidity and nutrient deficiencies limit crop yields in most developing countries. The consequences of poor yields include food insecurity, economic hardship, further deforestation, and increased soil exposure, erosion and downstream pollution. Upon overcoming soil acidity and nutrient constraints, new cropping strategies are possible, products and services are diversified, vegetative soil protection increases and off-site nutrient transport is minimized. However, the knowledge requirements to properly diagnose and prescribe best management alternatives for location-specific soil acidity and nutrient problems throughout the world exceed the capacity of any human expert. Numerous combinations of crops, social, political, economic and resource conditions must be considered. Scarcity and cost of experts can be alleviated if the required knowledge is organized in a manner accessible to inexperienced personnel. When combined with local data and observations, decision support systems (DSS) make this knowledge available for agriculturists to choose appropriate management strategies.

Nutrient interaction problems are of such complexity that they need to be addressed simultaneously. This integrated nutrient management decision support system (NuMaSS) is a tool that diagnoses soil constraints and selects the appropriate management practices, based on agronomic, economic and environmental criteria, for location-specific conditions.

Project Objectives

1. Improve the diagnosis and recommendations for soil acidity and nutrient problems by identifying and resolving knowledge gaps through extensive literature reviews and, when necessary, developmental research;
2. Develop an integrated computerized knowledge base for diagnosing and recommending practical solutions to soil acidity and N and P problems, which considers location-specific differences in resource availability, soil, climate, crop and management factors; and
3. Develop auxiliary tools to the integrated knowledge base to enable agriculturists to diagnose and solve soil acidity and nutrient problems that predominate within the social, economic and agronomic conditions of their regional domains.

Strategy

Three existing nutrient decision support systems, Acid Decision Support System (ADSS), Nitrogen Decision Support System (NDSS) and Phosphorus Decision Support (PDSS), have been reprogrammed as modules into an integrated user interface (NuMaSS). This is the third release of NuMaSS (Version 2.0). The first version, which was called IntDSS Version 1.0, was beta tested by soil fertility experts. Some of the major errors detected in the first release were corrected in the second version (NuMaSS 1.5). In the third version (NuMaSS 2.0), which has also been reviewed by users, the three soil constraints are diagnosed and predicted individually within the system. However, the modules are fully integrated in the *Economics* section.

NuMaSS MODULES

Introduction

The NuMaSS is a synthesis of five distinct programmatic sections - *Geography*, *Diagnosis, Prediction*, *Economics* and *Results* – each differentiated by a tab. You will be asked for information through the use of input boxes. Not all input boxes need information for NuMaSS 2.0 to work. The input information needed for the integrated system to run is dependent on the information needed by the individual modules. Data bases have been constructed that will provide default values in some, but not all, input boxes. There are some input boxes that must be completed. For instance, in order for the acidity or phosphorus module to work you must either enter % clay or textural class, as well as other parameters. Necessary inputs for the nitrogen module consist of intended crop, crop yield, plant N content, and, if you use organic inputs, the amount of manure or residues that you apply. Depending on your location and crop, some other necessary inputs can be accessed from the data base. However, the precision of your N recommendation improves dramatically the more information you supply. Necessary inputs to the acidity module for a recommendation are soil order, crop critical % Al saturation, exchangeable Al, effective cation exchange capacity, bulk density and either % clay or textural class.

Geography: NuMaSS automatically starts on the *Geography* tab. *Geography* requires information on the **Region** (continent), **Country**, and **Agricultural Area** (basically defined by the rainfall regime). Inputs for all of these categories are accessed through the pull-down lists. Alternatively, the area you want to pick can be selected by using the interactive world map. To see your area more closely, click *Zoom In*. Conversely, to make an area smaller click *Zoom Out* or, to see the entire world map, click *Full Extent*. To select the area you want, simply move the cursor to that area and click *Select*. The corresponding, country and agricultural area will automatically be selected into the user-input boxes.

The region, country and, finally, the agricultural area can all be selected using the pull-down menus. There are three generic agricultural areas: humid tropical, wet/dry, and semi-arid. In some cases, when we have specific names that correspond to these agricultural areas, such as Cerrado or Guinea Zone, we have used these names. The three generalized agricultural areas were identified by country using the Climate, Continents and Islands map (Stricker and Rodriguez, 1991).

Diagnosis: Proceed to the *Diagnosis* section. This section allows users to identify soil constraints but does not give nutrient recommendations or economic analysis of nutrient application needs. Each constraint is treated differently in the *Diagnosis* section. *Diagnosis* provides an early indication of whether there is a nutrient management problem. If not, further data is not required and nutrient status is probably sufficient requiring no further attention. Much of the information entered in this section is used in

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** Stricker and Rodriguez, 1991. Climate, Continents and Islands (map). Gainesville, FL & Bogata, Columbia the *Prediction* and *Economics* sections. Unless the crop to be grown is a legume or the field is coming out of long-term fallow, most cropping systems will be N deficient. Thus the *Diagnostic* section for the Nitrogen module is used primarily to determine the prior land use and to collect information for the *Prediction* section. The Acidity module uses the information obtained in *Diagnosis* to determine the amount of acidity that needs to be neutralized. The *Diagnosis* section should be filled out as completely as possible before continuing on to the next sections.

There are four subsections in *Diagnosis*: *Intended Crop*, *Previous Cropping*, *Soil* and *Plant*. Start with the *Intended Crop* page. Proceed through the *Diagnosis* section, answering questions as fully as possible.

Depending on your selections, different input boxes will become visible. Many of these input boxes have associated default values that may be provided as a guide from the data tables. If a default value is available, a small check box will be activated next to the default value in red. When the default box is activated, you can click on the checkbox to pull the default value into the input box. If you do not like the default value, simply type over the value. The data in the data tables have been gathered through literature reviews or, in some cases, based on expert opinion. (See the section on data base description for more specific information on how the default data is derived.)

Intended Crop
The one parameter that you MUST enter is **Crop**. This is the crop you intend to produce. Once you have selected the "Crop", the *Prediction* section will be available. The **Target yield** and **Al Saturation** input boxes must also have values; otherwise the program cannot provide answers.

If you are in a humid tropical or wet dry agricultural area, peach palm is one of the crops provided in the crop list. NuMaSS 2.0 will not provide a diagnosis for the nursery phase of peach palm, but it will provide information for the other three growth phases.

Previous Cropping
This page collects your previous crop information: crop, yield, fertilization history and other necessary information. Again, input boxes change depending on the selected crop and many of these boxes have associated default values.

Soil
Soil Order is the first input box on this page. The eleven soil orders listed in the U.S. taxonomic system are available for selection along with "Unknown" and "Other" categories. "Unknown" implies that you do not know what the category is, and "Other" indicates that you may know your category but it is not listed. There are never default values associated with "Unknown" or "Other.

You can either use your own soil data (select "use your site specific soil data") or use soil pedon data derived from The United States Department of Agriculture Natural Resource Conservation Service's National Soil Characterization Database (select "use soil pedon data"). Only data from the tropics are included in the pedon database. Data were screened by location criteria for either latitude and longitude coordinates or description of a particular location. Soils data that did not meet the location criteria were omitted from our soil pedon data table.

There are three helps screens available. The "Soil Order Info" help screen explains the major divisions of soils within the U.S. Taxonomy classification. The help screens "Soil Chemical Property Info" and "Soil Physical Property Info" describes soil input information.

Plant
There are three subtabs in the *Plant* section: *Plant Analysis*, *Nutrient Deficiency Symptoms*, and *Indicator Plants*. The *Plant Analysis* tab displays critical tissue nutrient levels for the previous crop. You can either use the defaults or your own values. Crop nutrient deficiencies are displayed for the previous crop on the *Nutrient Deficiency Symptoms* page. Plants, other than the crop, can often suggest nutrient management problems. These plants are viewable on the *Indicator Plants* page.

When you are through with the *Diagnosis* section, you can either proceed on to *Prediction* or you can select the "Run Diagnosis" button found in the upper right-hand corner of NuMaSS 2.0. Clicking "Run Diagnosis" analyzes the data entered during *Diagnosis* and finishes with the results of the *Diagnosis* module. The diagnosis results are displayed in the *Results* section, under *Diagnosis*/*Summary.* The Diagnosis is the likelihood of an acidity, nitrogen or phosphorus constraint for the intended crop based on Bayesian conditional probabilities for each of the diagnostic factors. Probability values for diagnostic factors are based on extensive surveys of nutrient management "experts" throughout the tropics. A conclusion of the likelihood of each nutrient constraint is provided in a tabular format in the *Diagnosis/Summary* section. The final probability for lime, P and N are based on the cumulative probability for information provided on all factors. The *Diagnosis/ Summary* also alerts you to conflicts in information and warns you about other data needed for Prediction.

The input values you used for making the diagnosis are found under *Results*/*Diagnosis*/*Values*. The program evaluates or re-evaluates the data entered only after selecting "Run Diagnosis", which means that every time you change an input value, you must click the "Run Diagnosis" button again.

Prediction: Proceed to the *Prediction* section by clicking the *Prediction* tab. The *Prediction* section recommends the amount of nutrients (N and P) and lime needed to produce the target yield. Economics and interaction between the nutrients are not considered in the *Prediction* section.

There are three subsections in *Prediction*: *Organic Application*, *Lime Application*, and *Nutrient Application*. Enter the available information. Defaults may be available for some, but not all, entry boxes. Prediction results will be displayed after clicking the "Run Prediction" button. The results are the nutrient recommendations without consideration of economics. Two sections will appear in the *Results/Prediction* section: *Summary,* which is the summary of the results, and *Values*, which is the display of the inputs used in *Prediction*. In addition, there are three additional pages within the *Results/Prediction*: *Nitrogen Report, Acidity Report, and Phosphorus Report.* The *Nitrogen* and *Acidity Reports* display either the calculations or the logic used in making the lime and N recommendations. The *Phosphorus Report* simply restates the P recommendation found in the *Results/Prediction*/*Summary* page.

Economics: The *Economics* section considers costs and revenues associated with nutrient applications. The results from the *Economics* section will help you determine whether or not to apply the amounts of fertilizer recommended. There is one input page in the *Economics* section. Please enter costs and prices and further information for additional analyses. When you are through entering information, click the "Run Economics" button to view the economic analysis of the different lime and nutrient applications. The output information is available in the *Results/Economics/Summary* section.

Unlike the other sections, however, the *Economics/Summary* section is interactive. The upper part of the *Economics/Summary* output is a standard section that calculates the nutrient amounts, costs and revenues for the target yield you entered in the *Diagnosis* section. Below the standard section is an options section that allows you to review costs and revenues under four different scenarios. First, you can select to compare the returns at the target yield goal for other types of fertilizers and/or change the prices of these fertilizers. Once you have selected the option and changed any inputs that are allowed, press the “compare” button next to the “options” box for a new analysis. Second, if you have a limited amount to spend, you can find the most profitable combination of inputs given your cash constraints. If you have a fixed amount of fertilizer or lime, you can also use the economics section to find the best combination of additional amendments given your fertilizer constraints. Fourth, you can change all fertilizers and prices to find best profit, regardless of your target yield.

For both the “fertilizer” and “cash constraint” options, the fertilizers and prices of the fertilizers are fixed from whatever previous option was selected. To change the types of fertilizers or the costs, click on either “best profit” or “compare fertilizer mixes” and then click back on either “fertilizer constraints” or “cash constraints.” You will now have the fertilizers and costs that you want. You may also want to reset your target yield equal to the most profitable yield found in best profit, then re-examine comparisons of fertilizers, cash constraints, or fertilizer constraints.

Another dynamic feature in the economics section can be found by clicking on the “Response Curve” box near the top of the screen. Use your mouse to drag the slider bar at the bottom of the page. Best yield is where the curve kinks, but best yield is not always the best profit.

Results: The *Results* section presents conclusions from the *Diagnosis, Prediction*, and *Economics* sections of NuMaSS 2.0. You can press the run button after each section (*Diagnosis, Prediction* and *Economics*) or you can wait until you have entered all the information required in all three sections. The conclusions will only be displayed after running the program using the "Run" buttons. Results for each of the model components (*Diagnosis, Prediction*, and *Economics*) are displayed separately within *Results* under *Summary*. For all three sections, the input values you used are found under R*esults*/*Values*.

Acidity Module
The Acidity module is designed to help you diagnose and correct soil problems due to Al toxicity and/or deficiencies of Ca and Mg. The primary approach used in the evaluation of soil acidity problems is to compare existing soil levels of Al with values where production of the intended crop is not limited. The knowledge for Al-based soil acidity management centers on soils belonging to the Alfisol, Inceptisol, Oxisol and Ultisol orders of the U.S. Soil Taxonomy. Although most soils belonging to the Aridisol, Mollisol, and Vertisol orders and many in the Entisol orders are not naturally acid, Al-based management can also be used to correct the acidity developed through their intensive agricultural use. Diagnosis and subsequent prediction and economic analysis of soil acidity problems, therefore, only exclude the Andisol, Gelisol and Histosol soil orders.

Diagnosis: the diagnosis requires the selection of an intended crop and the threshold or critical level of % Al saturation of the soil cation exchange capacity above which the crop's yields are depressed. Default critical % Al saturation values are provided for each crop and some cultivars, but the user has the option to specify a different value that may be more appropriate for their particular crop cultivar or site-specific conditions. Although not mandatory, information about the agricultural area, cropping history, soil order, soil and plant tissue analysis, nutrient deficiency symptoms and presence of plants indicative of acid soil conditions are also used and will improve the evaluation of soil acidity problems. Furthermore, considerations on liming in *Prediction* and *Economics* have minimum data set requirements that include some of the information requested in *Diagnosis*.

Among the soil analytical information there is a hierarchy in the data that is used. Preference is given to data needed to calculate the soil's Al saturation %, namely the exchangeable acidity (Al + H) extracted with a neutral unbuffered salt solution and the effective cation exchange capacity (ECEC). In the absence of this information, the % Al saturation of the soil can be estimated from soil pH in water through a relation developed across liming experiments in Africa, Asia and Latin America. If Al saturation % cannot be calculated or estimated from soil pH, soil Ca and Mg data will be used to evaluate the acidity problem. Potential deficiencies of Ca and Mg for the intended crop also are evaluated whenever the user provides soil or plant tissue data for these nutrients.

Prediction: If the soil's Al saturation % is greater than the critical value for the intended crop or soil Ca supply is limiting then a lime application is suggested. Estimation of the lime needed to reduce the soil's Al saturation % to the critical level of the intended crop is based on a modified version of the equation developed by Cochrane et al. (1980). Rather than liming soils to neutralize all of the exchangeable acidity, the equation computes the lime needed to only neutralize the quantity of exchangeable acidity that exceeds the intended crop's tolerance level. The original equation proposed a constant lime factor (LF) of 1.8 equivalents of $CaCO_3$ to neutralize each equivalent of exchangeable acidity.

Through our review of lime trials with soils in the tropics, we found that the lime factor differed among soils and between high (>20) and low (<20) % Al saturation values within a soil. The difference in lime factors among soils in the high (>20) % Al saturation range was related to an index of the soil's clay activity estimated by the $cmol_c$ of whole-soil ECEC/l or kg of clay in the soil. The efficiency of $CaCO_3$ in neutralizing exchangeable acidity of soils with low "clay-based ECEC" was lower (higher LF value) than in soils with high "clay-based ECEC" values.

The original equation of Cochrane et al. (1980) was, therefore, revised so that suggested lime requirements include consideration of differences in lime factors among soils as well as between high and low % Al saturation within soils. The complete revised equation is

$$LR = LF[Al - (TAS(ECEC)/100)] + 7.5[(19 - TAS)ECEC/100]$$

where
LR = lime requirement in $CaCO_3$ equivalents, t ha^{-1};
LF = lime factor, equivalents of $CaCO_3$ / equivalent of exchangeable acidity, for neutralization of soil exchangeable acidity in the range of 20 - 100% Al saturation; if [ECEC(100/%clay] < or = 4.5, then LF = 2.5; otherwise LF = 1.3;
Al = soil extractable acidity with M KCl, cmol/l or kg;
TAS = targeted or critical % Al saturation for the intended crop;
ECEC = effective cation exchange capacity of the soil, cmol/l or kg of soil; and
7.5 = lime factor for neutralization of soil exchangeable acidity in the range of < 20% Al saturation.
Information for Al, TAS and ECEC are entered in the *Diagnosis* section.

There are two conditions where a fixed amount of lime is suggested instead of the value derived from the equation:
•soils with low ECEC where equation-derived lime requirements for acid-sensitive crops would not provide sufficient Ca; a lime application equivalent to 1 t $CaCO_3$ ha^{-1} is suggested.
•current evidence suggests that yield responses of peach palm to lime are associated with soil Ca and Mg deficiencies rather than Al toxicity. A lime application equivalent to 1 t $CaCO_3$ ha^{-1} is suggested when soil Ca is less than 0.8 cmol/l or kg.

**Cochrane, T.T., J.G. Salinas and P.A. Sanchez. 1980. An equation for liming acid mineral soils to compensate for crop aluminium tolerance. Trop. Agric. 57:133-140.

The final lime recommendation includes adjustments of the value predicted by the equation for the following factors:
•depth of lime incorporation - when the depth is different from 15 cm an adjustment is made through the ratio “(intended depth/15)”;
•bulk density - soil exchangeable acidity and ECEC data are converted from weight-by-weight lab units to weight-by-volume at the field level;
•lime quality - the lime recommendation by the equation is for pure $CaCO_3$ with a fine particle size (100% finer than 60 mesh). Information on the quality of lime material that will be used can be provided as either (a) the particle size distribution and the $CaCO_3$-equivalence or (b) the effective $CaCO_3$ content which is the product of the particle size and $CaCO_3$-equivalence.
•lime effect of organic inputs - the lime requirement is reduced by 1 t ha^{-1} for every 10 t ha^{-1} (fresh weight basis) of applied organic material.

Information on depth of lime incorporation and lime quality are entered on the *Lime Application* page in the *Prediction* section. Bulk density information is entered on the *Soils* page in the *Diagnosis* section, and information on organic inputs is entered on the *Organic Application* page in the *Prediction* section.

The final, adjusted lime recommendation is accompanied by comments and suggestions on lime management for the particular crop and soil conditions. Information on residual effects of the suggested lime application to subsequent crop cycles and years is provided as predicted % Al saturation values for the soil up to the 4^{th} year after liming. If data for Ca and Mg content are provided for both the soil (in the *Diagnosis* section) and the lime material (in the *Lime Application* page of the *Prediction* section), the *Soil Acidity Report* provides estimates of soil Ca and Mg levels after liming and the suitability of the soil Ca:Mg ratio for the intended crop.

Nitrogen Module
The Nitrogen module is primarily designed to help you determine appropriate nitrogen fertilizer rates after accounting for any organic applications. The Nitrogen module depends on an extensive data base.

Diagnosis: N is almost always deficient in tropical soils unless a legume is being grown or the crop is preceded by a fallow or green manure system. Therefore, diagnosis of N deficiencies almost always produces the need to add N.

Prediction: Unlike most other nutrients, there are few reliable soil tests to determine crop N needs. This is particularly true in humid regions where N can be readily transformed and moved below the rooting zone. Generally N fertilizer recommendations are based on extensive data sets developed over many years.

When extensive field data is not available for determining N fertilizer rates, crop N fertilizer needs can be calculated using available soil and crop data. The equation below predicts the N fertilizer requirement for crops, except grain legumes, peach palm, and cotton. Since grain legumes fix their own nitrogen, no fertilizer nitrogen calculations are made for these crops. The algorithms for peach palm and cotton will be discussed at the end of this section.

$N_{fert} = (Y_r{*}N_{cr}) - [(N_{soil}) + (N_{residue.}{*}C_r) + (N_{manure}{*}C_m)] / E_f$

Equation abbreviations	**Definitions**
N_{fert}	N fertilizer needed
Y_r	Target dry matter yield, both vegetative and/or reproductive and/or total dry matter
N_{cr}	Concentration of nitrogen (%N) in vegetative and/or reproductive and/or total dry matter
N_{soil}	Nitrogen absorbed by the crop that is derived from soil organic matter and previous crop residue mineralization, and from atmospheric deposition during growing season
$N_{r.}$	Nitrogen mineralized from green manures or residues, such as stover or compost that are added to the field.
C_r	Proportion of nitrogen mineralized from green manures or residues that are absorbed by the plant.
N_{manure}	Nitrogen mineralized from manure
C_m	Proportion of nitrogen mineralized from manure that the crop absorbs
N_{fert}	N fertilizer needed
E_f	Fertilizer efficiency

Determining Crop N: The first step is to determine the total crop N need. The equation for this determination is: Total Crop N Needs = $Y_r * N_{cr} = Y_g{*}\%N_g + Y_s{*}\%N_s$

Abbreviation	**Definition**
Y_r	Total dry matter
N_{cr}	Nitrogen concentration in the total plant
Y_g	Reproductive yield
$\%N_g$	Nitrogen concentration in the reproductive portion of the crop
Y_s	Vegetative yield
$\%N_s$	Nitrogen concentration in the vegetative portion of the plant

The amount of additional N needed to produce the target yield that you want is a function of the capacity of the soil to supply N and the total amount of crop N needed. In order to determine the total crop demand for N, it is important to know the yield that you are trying to obtain so that you can determine the amount of N fertilizer you will need. You will obtain better results if you enter either the total amount of dry matter or yield that you realistically believe you can obtain. If you do not enter this information, a default value will be obtained from the data base for your location, based on region, country and/or agricultural area. Since total crop N is a function of both total crop dry matter and the N content, if you do not have information for N content, again a default value will be obtained from the data base. The input information necessary to determine the amount of N that the crop needs is entered in the *Diagnosis* section of NuMaSS 2.0.

Determining Crop Available N: Once the amount of N is calculated for the target yield, the Nitrogen module calculates the amount of N available to the crop from the soil (N_{Soil}), manure (N_{Manure}) , organic amendments ($N_{Residue}$), and green manure crops ($N_{Residue}$). The equation used to calculate crop available N is:

$$\text{Crop available N} = N_{Crop(available\_to)} = N_{Soil} + N_{Manure} + N_{Residue}$$

Determining Soil N: There are four different methods that you can use to determine the amount of N supplied by the soil (N_{Soil}). The program automatically selects the method for calculating N_{Soil} based on the data availability. The hierarchy for determining N_{Soil} is outlined below. If sufficient data is available for Method 1, then that is the method used. However, if there is insufficient data the program will continue sequentially checking for available data until a method can be found. The precision for calculating N_{Soil} changes as the program moves through the methods. Method 1 is the most precise calculation of N_{Soil} , Method 4 is the least precise.

Soil N is pulled in the following hierarchy:

1. The amount of N contained in an unfertilized crop gives you an indication of the N supplying capacity of the soil. If the previous crop and the current crop are the same and the previous crop was not fertilized, then soil N can be calculated. You will have already entered this information in the *Diagnosis* section under *Crop History*.
2. If you know your soil N value, enter this value in the *Prediction/Fertilizer Application.*
3. If you do not know your soil N value, you may prefer to use the default N value that is derived from the default table. You simply click on the default check box. However, default soil N values are not available for all locations.
4. The least precise method for determining soil N supply is by calculating N mineralization either from soil % organic matter, %C or %N content. The default rate of mineralization is 2% per year multiplied by the proportion of months the crop is grown. User supplied soil N, C, or organic matter content will come from the *Diagnosis* section. A default value for either soil %N, %C, or % organic matter will be available for many soils, if you do not have your own value.

Determining Manure N: If manure material is added in the current crop production season, then the N supplied by the manure must be accounted for. Information on manure is entered in the *Prediction* section under *Organic Application*. The amount of N from manure can either be calculated from information you supply or from the default data tables. At a minimum, you must supply the type of animal from which the manure comes and the amount of manure you are adding.

Determining Residue N: Green manures that remain in place or residues, such as stover or compost, that are moved from one location to another also provide N to the crop and thus reduce the amount of fertilizer that must be added. You will enter information on green manures in the *Diagnosis* section under *Previous Cropping*. You will be asked about residue information in the *Prediction* section under the *Organic Application*. Again, you will be asked to supply specific information, but if you do not have this information, values may be supplied through the data tables.

Determining Fertilizer Requirement: At the end of the *Prediction* section, the crop N requirement and N sources (N supplied by the soil and added organic sources) have been determined. By subtracting the amount of N supplied by the soil and organic sources from the amount of N needed by the crop at the target yield, the amount of extra N needed as fertilizer is calculated. To determine fertilizer N, the amount of N needed by the crop is divided by the efficiency of the N fertilizer (See *Prediction* section – *Fertilizer Application*). You can either supply the fertilizer efficiency value or you may be able to access a value from the data base. Fertilizer efficiency must be supplied for the system to provide a N fertilizer recommendation.

Cotton Fertilizer Requirements: The nitrogen fertilizer rates for cotton are calculated by using the target yield and a nitrogen factor. The nitrogen factor accounts for nitrogen coming from the soil as well as the inefficiency of fertilizers. There are two nitrogen factors: 1) histosols = 0.06 kg N/kg yield, and 2) all other soils = 0.08 kg N/kg yield. Thus the equation is N fertilizer needed = Yield (kg/ha) * N factor (kg N/kg yield).

Peach Palm Fertilizer Requirements: Because peach palm is a perennial plant, it has different growth stages and nitrogen needs. We consider : 1) establishment (first year after transplanting or first heart-of-palm harvest, whichever comes first), 2) fast growth stage (when the plants are still gaining vegetative matter), and 3) mature stage (the stage at which biomass steady-state is reached). Plant density is an important variable in the fast growth stage.

Based on some studies conducted by Adrian Ares and collaborators in Costa Rica, the following relationship was found between age (x) of the peach palm stand and amount of nitrogen in the stand (y): Nitrogen in the Stand (kg N/ha) = 43 + 5.7y for low density, and 43 + 14.7y for the high density.

This implies that during the establishment phase of peach palm, the crop must absorb over 43 kg N/ha. It takes a low-density plantation 8 years after establishment to reach maturity. Thus, each year for 8 years the plantation must take up an additional 5.7 kg

N/ha. In high-density stands, it only takes 3 years for the plantation to reach steady-state or maturity, thus each year for 3 years the stand must add an additional 14.7 kg N/ha to increase the standing biomass. These additional nitrogen needs must be met for the plantation to reach maturity.

After establishment, heart-of-palm harvest starts and nitrogen accumulated in the meristems that are harvested and removed from the field must be added back into the system. Research from Costa Rica suggests that for each heart-of-palm harvested and removed from the field, the crop needs 0.0178 kg N/ha. The amount of residue returned to the system from the harvesting of heart-of-palm is 0.0148 kg N/ha for each heart-of-palm harvested times a nitrogen recycling factor of 80%. Nitrogen fertilizer efficiency (Ef) was found to be approximately 35% in these systems.

Based on this preliminary research we have proposed the following nitrogen fertilizer equations for peach palm and are using these equations in NuMaSS 2.0.

- Nitrogen fertilizer (establishment) = 43/Ef
- Nitrogen fertilizer (fast growth, low density) = ((0.0178 * # harvested heart-of-palm) + 5.7) – (Soil N + (0.0148 * # previously harvested heart-of-palm * 0.80))/Ef
- Nitrogen fertilizer (fast growth, high density) = ((0.0178 * # harvested heart-of-palm) + 14.7) – (Soil N + (0.0148 * # previously harvested heart-of-palm * 0.80))/Ef
- Nitrogen fertilizer (mature growth) = (0.0178 * # harvested heart-of-palm) – (Soil N + (0.0148 * # previously harvested heart-of-palm * 0.80))/Ef

Phosphorus Module

Objectives:

The purpose of the Phosphorus (P) module is to:

1. Diagnose whether the soil P supply is sufficient for your intended to crop to grow and yield at its capacity.
2. If the soil P supply is not sufficient, predict the amount of P fertilizer necessary to alleviate the deficiency.
3. Provide the amount of fertilizer and expected yield increase to the economics module for an economic analysis.
4. The P module has no recommendation mode in NuMaSS 2.

Diagnosis: The diagnosis of whether your soil P supply is sufficient is based on information that includes general knowledge about the area, cropping history, crop observations/symptoms, soil and plant tissue analyses, and the presence of certain indicator plants generally representative of soil P status. The minimum dataset to diagnose a phosphorus deficiency includes: 1) intended crop, 2) soil test P method, 3) soil test P value, and 4) percent clay content. Additional data is needed in the *Prediction* and *Economics* sections in order to complete a recommendation.

Prediction: If the extractable P level of your field is less than the P critical level, then a P prediction will be suggested. To make a P prediction further information is needed on fertilizer type, application method, and application depth (*Fertilizer Application* tab).

The Phosphorus module also makes an estimate of the extractable P level after the crop is harvested. This option provides the results needed to estimate the costs of maintaining extractable P at the critical level and the economic consequences of doing so. The estimate of extractable P after the crop is harvested should also be useful if a crop with a different critical soil P level follows the present crop.

When the minimum dataset is provided, the Phosphorus module estimates both the critical P level for the crop and the buffering coefficient. If the user has more specific estimates of these coefficients they can be entered directly in the *Fertilizer Application* page and the subsequent calculations will use the revised values. Our experience is that making such predictions of the fertilizer P requirement involves much uncertainty, hence we have implemented an estimate of the combined uncertainty of all factors that contribute directly to the calculation of the P prediction.

Integrated Economic Analysis

It is within the *Economics* section that nutrient predictions are integrated. Although each amendment has an optimum rate, optimum rates may not be economically the best solution. In addition, amendment types (such as the types of fertilizer or lime sold), the quantities of the amendments, the price of the amendments, or the amount of cash a producer may have available, can determine the amendment rate. Thus, this section is critical in determining useable amendment rates based on prevailing market conditions.

Each nutrient response is based on an underlying linear-plateau production function, Y = min (a + bx, T) where "Y" is the yield, "a" is the intercept, "b" is the slope coefficient and "T" is the optimum yield. We are assuming the von Liebig law of the minimum response. This assumes that one nutrient is most limiting and it is only when that nutrient need is met that other nutrients contribute to yield. In order to do the economic analysis in NuMaSS 2.0, we have assumed that each nutrient is independent, although we recognize that this may not be true.

Return attributable for each of the inputs is based on the marginal value product compared to input cost. Marginal value product (MVP) is the output price (P) times the derivative of Y with respect to the input (b). In this case, the derivative is always equal to "b", and thus marginal value product is MVP=Pb. The most profitable level of each input is found where MVPx = Px.

These are the basic equations underlying the integrated economics section. You must enter the optimum yield, the minimum yield (for cotton only), cost of the amendments and price of the commodity. Entering the cost of lime or fertilizer application is optional. Once you have entered these values, simply click the "Run Economics" button and the program will display the *Results/Summary* screen for Economics. Displayed on the page is the target yield level for which the economic solution has been determined, the amount of the amendments needed, the cost of amendments (on a per hectare basis) and the net return for the amendments.

Unlike the other result pages, the *Economics/Result/Summary* page is interactive. There are four options described below:

Compare Fertilizer Mixes**:** This option allows you to compare different fertilizers – both elemental and mixes (or blends). You will have the option of selecting only elemental, only mixed, or both types of fertilizer using the drop down menus provided. You will need to enter the cost of the fertilizer on a per kg basis. You can also change the price of the lime, although you cannot change the type or quality of lime that you are using. To change your lime type or quality you will need to return to the *Prediction/Lime Application* page. Lime is priced by the ton. Click on the "compare" button for the output. The economic solution is given for the target yield you are trying to obtain. If you have selected to use fertilizer mixes, as opposed to only elemental fertilizers, the amendment amounts may oversupply one of the nutrients. The header, "Excess Nutrients" displays the amount of excess N or P that you have applied due to the use of a mixed fertilizers. If excess nutrients are supplied, this may or may not affect your net return. Finally, the program computes the optimum inputs for your target yield, which may not be the most profitable yield to target. Your results in this section will not be the most profitable combinations if target yield exceeds best profit yield.

Compare Fertilizer Constraints: This option allows you to enter different amounts of fertilizer. In particular, this option was designed for areas where fertilizer is often in short supply. The type and price of fertilizer and the price of lime must be selected in the "Compare Fertilizer Mixes" option. Then proceed to the compare fertilizer constraints option. Change the amount of fertilizer or lime you have available. The solution will tell you the yield you can obtain with that type and amount of fertilizer and the amount of lime you have selected. Click on the "compare" button for the output. The economic solution works toward the target yield. You may, however, have insufficient fertilizer to reach the target yield. Therefore, you will have a reduced yield level. This yield level will be listed. Your results will not be the most profitable combination if your fertilizer-constrained yield is greater than the best profit yield; results will be the best combination of inputs to meet your fertilizer constraint.

Compare Cash Constraints: This option allows you to enter the amount of money you have available to spend on amendments. The type and price of fertilizer and the price of lime must be selected in the "Compare Fertilizer Mixes" option. Then put in the amount of money you have available in the "cost" input box. Click on the "compare" button for the output. The economic solution works toward the target yield. You may, however, have insufficient money to reach the target yield. Therefore, you will have a reduced yield level. This yield level will be listed, as well as the amount of fertilizer and lime that can be purchased with the amount of money that you have. Your results will not be the most profitable combination if your cash constrained yield is greater than the best profit yield; results will be the best combination of inputs to meet your cash constraint.

Compare Best Profit: This option allows you to enter the type and price of fertilizer and the amount of lime. Click on the "compare" button for the output. This option works towards the best profit level. This may or may not be optimum yield or target yield. The yield level and fertilizer and lime amounts will be listed for the best profit.

In addition to the interactive options, there is information provided about the value of any organic sources you have used (*Organic and Residual Effects*). A note will tell you your savings value in fertilizer N and lime from organic applications, and also savings in lime costs to crops after the intended crop due to the residual effects of these amendments.

In addition to the *Economics/Result/Summary* page, there is also an interactive graph (*Response Curve*) that allows you to view the yield response curve at different amendment rates. These amendment values are elemental and do not reflect fertilizer type. As with the other *Result* sections, there is a *Values* page that displays all the values you are using.

DEVELOPMENT of NuMaSS

Version 1.0 (Release September 1999)

Interface

- Paper prototyped the system.
- Developed tab structure.
- Developed input boxes.
- Developed sections: “Geography”, “Diagnosis”, “Prediction”, “Economics”, and “Results”
- Developed data base structure.
- Started collecting data for the data tables.
- Obtained the USDA-NRCS data base for tropical soils and eliminated all entries that did not have a locational indicator.
- Provided preliminary information on the system.

Acidity Module

- Translated the Acidity Decision Support System (ADSS, version 5.0) from the EXSYS and Pascal language into Delphi.

Nitrogen Module

- Developed “Prediction” N algorithms for 12 of the crops.
- Started accumulating crop information for Crop_yield data table.
- Developed economic analysis for N.

Phosphorus Module

- Phosphorus Decision Support System (PDSS), version 1, was first released in January, 1992. Three modules were implementation in PDSS: Diagnosis, Prediction, and Economic as a nutrient management system for phosphorus.
- NuMaSS, version 1.0, includes “Diagnosis”, “Prediction”, “Economic Analysis”, and “Recommendation” from PDSS (Phosphorus Decision Support System, version 2).

Version 1.5 (Release May 2000)

Interface

- Added a component that allowed either "." or "," to be used for the decimal delimiter
- Provided help modules on such topics as "Soil Taxonomy", "Soil Testing", "Environmental Affects of Fertilizers".
- Provided a range check function that notifies users when a input value is beyond the normal range.
- Changed the name from Integrated Soil Nutrient Management Decision Support System (IntDSS) to Nutrient Management Support System (NuMaSS).
- Save and retrieve feature was added, allowing users to save input data and retrieve it.
- Print function for "Results" section was added.

Acidity Module

- Corrected calculations for "Economic Analysis".
- Revised diagnosis and prediction for potato.

Nitrogen Module

- Input boxes for nitrogen entries were programmed to be activated only when necessary.
- Corrected N inputs for leguminous crops.

Version 2.0 (Release September 2002)

Interface

- Streamlined interface by reducing 18 tabs as well as a number of input boxes.
- Added over 70 images of plant nutrient deficiencies and related previous crop to these nutrient deficiencies.
- Added over 5 images of indicator plants.
- Added close to 500 records to the Crop_yield table. There are over 20 fields for each record. The table primarily provides default yield information and N data for the 18 crops in the system.
- Added agricultural regions to each country.
- The map became functional so that users can click on a country to pull up information in the "Geography" section.
- Viewable data base records.
- Added multiple popup warning messages when there is a user input error.

Acidity Module

- "Diagnosis" was upgraded to include Bayesian probabilities for soil acidity.
- Reprogrammed "Diagnosis and Prediction" as distinct entities to ensure compatibility with Nitrogen and Phosphorus modules.
- Developed algorithms for relations between soil pH and % Al saturation based on data from the tropics.

- Assembled critical soil % Al saturation data for crop cultivars and diagnostic foliar Ca and Mg levels.
- Expanded acidity module application for 4 additional soil orders in the U.S. Soil Taxonomy.
- Revised lime factor algorithms in "Prediction" to account for soils with high and low activity clays.
- Revised algorithms for adjustment of lime quality to account for different types of information available to users.
- Developed algorithms for peach palm in "Diagnosis" and "Prediction" based on soil and plant Ca and Mg deficiencies.
- Developed algorithms for "Economics" to estimate location-specific yield responses to liming for all crops.
- Developed algorithms to estimate savings in lime due to organic inputs in "Economics."
- Revised algorithms, based on analyses of long-term trial data in the tropics, to estimate future cost savings from applied lime in "Economics."

Nitrogen Module

- "Diagnosis" was upgraded to include Bayesian probabilities for N.
- Peach palm, cotton, and tuber algorithms were added to "Prediction."
- Nitrogen economic algorithms were developed for all crops.
- Developed algorithms to estimate savings for N due to organic inputs in "Economics."

Phosphorus Module

- Includes data from Mali, West Africa for sandy soils (5-12% clay) and improved data for soils with high clay content (60-80%) from S. America and S.E. Asia. This data is used to better estimate P critical level and P buffer coefficients.
- Additional crops are now included in estimates of P requirement: cotton, potato, and peach palm.
- Removal of Economic options, Residual effects, and Phosphate fertilizer material choice.

Economics

- The "Economics" section was completely overhauled. The interface was dramatically changed to provide for integration of the three modules.
- Extensive cost and benefit programming for the integrated response functions of the three modules was developed and implemented in NuMaSS.
- A response curve for the "Economic" section was developed.
- Economic benefits of organic amendments were added.

DATA BASES for NuMaSS

Data Base Description

The NuMaSS data base is comprised of 19 data tables (see data structure tab). These data bases provide default values for some of the input variables or they provide critical information for the system. One data table, *Econ_output*, is created during the economic analysis. The information contained in this data table will change each time an economic analysis is performed.

Criteria for the default data depends on the available data, but, often, is a function of region, country, agricultural area, crops and soil (see data structure and data dictionary sections for more information). Most of the data tables described below can be viewed within NuMaSS 2.0. At the top left-hand corner of the program is the "Options" button. Press this and then go to select "View Data Tables." This list of data tables that can be viewed will be visible. Simply click on the table you want to view. The data table will "pop-up." Just click the "close" button of the data table when you are through viewing the table.

The geographical information provided by the system is located in the *Agroecosystems* data table. This table organizes the world by continents, countries within continents, and agroecoregions (humid tropical, wet/dry, and semi-arid) within countries. When regional names exist for an agroecosystem, for example the Amazon, that specific name is used rather than the more general agroecosystem name, such as humid tropical in this particular example.

The crops used in the NuMaSS are stored in the *Crop* data table. Crop data, such as optimal, average and minimum yields, has been and is continuing to be collected from published and gray literature. Considerable crop information has been added to the data base for cassava, cowpeas, maize, pearl millet, potatoes, sorghum, upland rice, wheat, pasture grasses and legumes, potatoes, yams and green manures (*Crop_yield*). There is less data available for the other crops, such as bambarra groundnut, cotton, mung beans, phaseolus beans, and soybeans.

Data on the nitrogen supplying capacity of manures (*Manure* data table) and legume cover crops (*Fallow_greenmanure* data table) has been collected and organized into the data tables. The *Manure* table lists the nutrient content of manure from different animal types. This manure information has been derived from tropical areas. Nutrient content of manures is highly variable. We have selected ranges in the middle and believe these to be best estimates. Nitrogen contributions from grain legumes to the preceding crop are calculated two ways – either using the stover or as a default value based on data from literature. These default values can be found in the *Crop_yield* table. *Fertilizer* table lists the elemental content of the different fertilizer types.

The soil pedon data contained in NuMaSS comes from United States Department of Agriculture Natural Resource Conservation Service's National Soil Characterization Database. The pedon data table in NuMaSS consists of only soil characterization data from tropical countries. We have excluded tropical pedons that do not have any spatial identification. This means that any pedons that did not have either locations or reference points (longitude and latitude) associated with them are not part of the *Soil_pedons* table.

Each soil pedon record consists of soils information (e.g. exchangeable cations, ECEC, bulk density, texture, etc.) based on layers. Depending on the pedon, there are 2 to 5 layers per pedon. Each layer has a thickness associated with it. When a soil pedon is selected (*Diagnosis/Soil* and *Soil Pedon*), the soil data of interest is calculated based on a soil depth of 15 cm. Therefore, if layer 1 is less than 15 cm, the default soil data will be the proportionate combination of data from layer 1 and layer 2 based on layer thickness. For example, if the first layer is 10 cm thick with a bulk density of 1.0 g cm^{-3} and the second layer is 40 cm with a bulk density of 1.5 g cm^{-3}, the bulk density displayed will be 1.17 g cm^{-3} for the 15 cm depth (1.0 g cm^{-3} for 10 cm and 1.5 g cm^{-3} for 5 cm).

Soil pedon default data is used by acidity, nitrogen and phosphorus, especially the acidity and phosphorus modules. As discussed above, default values for the soil properties displayed in the *Diagnosis* section of NuMaSS are based on a 15 cm depth. However, in the *Prediction* section, users select the depth of lime incorporation (*Lime Application*) and phosphorus incorporation (*Fertilizer Application*) separately. These depths of incorporation may be different from each other and they may also be different from the default depth of 15 cm. A different depth of incorporation will trigger a recalculation of the parameters of interest, based on the new depth. For example, if depth of incorporation in the *Lime Application* page is selected to be 20 cm, then the new bulk density (based on the example above) will be 1.25 g cm^{-3} (1.0 g cm^{-3} for 10 cm and 1.5 g cm^{-3} for 10 cm). This newly calculated bulk density will be used to calculate the liming rate. If at the same time, the depth of incorporation in the *Phosphorus Application* is maintained at 15 cm, then the bulk density value of 1.17g cm^{-3} will be used. Note that the bulk density values used to calculate the lime and phosphorus application rates are different. Because there are two different bulk density values, newly calculated values will not display. Soil depth for NITROGEN MODULE is always set at 15 cm and any default data derived from the *Soil_pedon* table will be based on a 15 cm depth.

There are three other soil tables that are part of the NuMaSS data base - *Soil_fertility*, *Soil_critical*, and *Bulk_density*. The *Soil_fertility* table contains information on the quantity of nitrogen mineralized by soils. Soil critical values for particular elements and crops are listed in the *Soil_critical* table and used for the lime and phosphorus modules. The *Bulk_density* table provides bulk density default values based on soil order and texture. The bulk density information for this table was gathered from the pedon table. Bulk density values were taken from the *Pedon* table and both average and median values were calculated. Because no differences were identified, average bulk density is used in the table.

Some soil nutrient deficiencies can be assessed either from pictures of plant nutrient deficiencies, pictures of indicator plants, or nutrient content of previously grown crops. The data tables associated with the plant images are *Indicator_plant* for the indicator plants and *Crop_observation* for the associated nutrient deficiency images. The *Crop_critical* data table contains the critical levels of nutrients for different.

Probabilities of a nitrogen, phosphorus or acidity problems associated with particular conditions are stored in the *Probability* table. Additional probability values for phosphorus are located in the *Prob_loc_order* table. The probability values from these data tables are used in the *Diagnosis* section to calculate the probability of a particular nutrient deficiency (or sufficiency). Values that are used to check the acceptable range of an input value are stored in *Range_check*. Tables used for the P module include *CV_paramter* and *PuptakeFactor*.

Data Base Structure

DATA STRUCTURE USED IN NuMaSS (8/10/02)

Crop
Crop
Variety
Scientific_name

Crop_critical
Crop
Variety
N_percent
P_percent
K_percent
Ca_percent
Mg_percent
S_percent
Zn_ppm
Fe_ppm
Mn_ppm
Cu_ppm
B_ppm
Tissue_type
Plant_development_stage
Reference_number

Crop_yield
Crop
Variety
Type
Region
Country
Agricultural_region
Agroecosystem
Soil_order
Rainfall
Average_yield
Optimum_yield
Average_vegetative
Optimum_vegetative
Average_total_drymatter
Optimum_total_drymatter
NUE_commercial
N_percent_vegetative
N_percent_reproductive
N_percent_total
N_legume_contribution
P_percent_vegetative
P_percent_reproductive
P_convert_factor
Harvest_index
Yield_no_fert
Reference_number

Soil_critical
Crop
Variety
Critical_element
AlSat_slope
Test_method
Soil_critical_level
Description
Reference_number

Soil_pedons
Id_ped
Layer_number
Thickness
Soil_order
Taxonomic_code
Taxonomic_name
Extractable_P
P_extractant
Percent_P_retention
K_exchangeable
Ca_exchangeable
Mg_exchangeable
Na_exchangeable
Al_exchangeable
Al_saturation
pH_water
ECEC
Bulk_density
Percent_clay
Percent_sand
Percent_silt
Percent_N
Percent_C
Mineral_family
Soil_temperature_regime
Region
State
Country
Location
Latitude
Longitude
Reference_number
ID

Bulk_density
Soil_order
Sandy
Loamy
Clayey

Soil_fertility
Soil_order (PK)
Region
Country
Agricultural_region
Soil_N
N_percent
Reference_number

Agroecosystems
Region
Country
Agricultural_region
Agroecosystem
Map_code

Fallow_greenmanure
Fallow_type
Region
Country
Agricultural_region
Soil_order
Length
Management_practice
Optimum_total_drymatter
N_percent_total
N_contribution
NUE_greenmanure
P_contribution
Lime_equivalent
Reference_number

Manure
Manure_type
N_percent
P_percent
Lime_equivalent
Ca_percent
Mg_percent
K_percent
NUE_manure
Reference_number

Fertilizer
Fertilizer
Fertilizer_type
N_percent
P_percent
K_percent
Ca_percent
Mg_percent
S_percent

CV_parameter
Crop
Parameter
Test_method
CV

Reference
Reference_number
Author(s)
Year
Title
Source

Crop_observation
Plant_image_name
Image_path
Crop_observation
Deficiency
Mn
A
P
N
Ca
Mg
K
Stage
Slide_source

Indicator_plant
Indicator_plant
Plant_image_name
Common_name
Region
Nutrient_deficiency_N
Nutrient_deficiency_P
Nutrient_deficiency_L
Reference_number

Probability
Variable1
Diagnostic_variable
A_deficiency
P_deficiency
N_deficiency
Ca_deficiency
Mg_deficiency
Reference_number (PK)

Prob_loc_order
Location
Country
Soil_order
Fertilization
Critical_element
Deficiency

PuptakeFactor
Crop
Convert factor

Range_check
Check_variable
Minimum_value
Maximum_value

Data Dictionary for NuMass

Field Name	Table(s)	Definition	Type	Unit	Length	Precision	Valid Values	Example

Data Dictionary for NuMaSS: 1/31/02 Version 2.0

Soil_order	Soil_pedons, Crop_yield, Soil_fertility, Fallow_greenmanure Prob_loc_order	Soil order listing within the US soil taxonomic system	Character		12	0		Ultisol
Id_ped	Soil_pedons,	NRCS pedon identification number	Character		7	0		9000616
Taxonomic_code	Soil_pedons	NRCS code for order/suborder/great group/subgroup	Character		12	0		V/US/HA/AA00
Taxonomic_name	Soil_pedons, Soil_fertility	NRCS Sub Group Name	Character		35	0		Typic haplustert
Layer_number	Soil_pedons,	Soil horizon	Numeric		2	0	1-10	2
Thickness	Soil_pedons	Thickness of soil layer	Numeric	cm	5	1	0.1-500.0	20.0
Extractable_P	Soil_pedons	Soil test P	Numeric	ppm	6	1	0.1-999.0	6.1
P_extractant	Soil_pedons	Type of P soil test extractant	Character		20	0		Bray1
Test_method	Soil_critical, CV_parameter	Soil extract for the critical element that is being measure	Character		15	0		Mehlich1
Percent_P_retention	Soil_pedons,	Single-point soil P sorption	Numeric	%	3	0	0-99	65
K_exchangeable	Soil_pedons,	Exchangeable soil K	Numeric	Meq/100 g	5	2	0.01-20.00	0.15
Ca_exchangeable	Soil_pedons	Exchangeable soil Ca	Numeric	Meq/100 g	5	2	0.10-50.00	5.00
Mg_exchangeable	Soil_pedons	Exchangeable soil Mg	Numeric	Meq/100 g	5	2	0.01-25.00	2.50
Na_exchangeable	Soil_pedons	Exchangeable soil Na	Numeric	Meq/100 g	5	2	0.01-99.00	0.90
Al_exchangeable	Soil_pedons	Exchangeable soil Al	Numeric	Meq/100 g	5	2	.01-99.00	1.00
Al_saturation	Soil_pedons, Soil_fertility	Percent Al saturation	Numeric	%	2	0	0-99	10

Field Name	Table(s)	Definition	Type	Unit	Length	Precision	Valid Values	Example
pH_water	Soil_pedons	Soil pH in water	Numeric		4	1	3.0-10.0	5.2
ECEC	Soil_pedons	Effective cation exchange capacity	Numeric	Meq/100 g	6	2	0.01-150.00	7.00
Bulk_density	Soil_pedons	Soil bulk density	Numeric	g/cm3	4	2	0.20-2.00	1.15
Percent_clay	Soil_pedons	Percent of clay	Numeric	%	3	0	1-100	35
Percent_sand	Soil_pedons	Percent of sand	Numeric	%	3	0	1-100	60
Percent_silt	Soil_pedons	Percent of silt	Numeric	%	3	0	1-100	60
Percent_N	Soil_pedons	Percent total soil nitrogen	Numeric	%	5	2	.01-10.00	0.10
Soil_N	Soil_fertility	Amount of soil derived nitrogen supplied to the crop	Numeric	kg/ha	3	0	1-100	30
Percent_C	Soil_pedons	Percent organic soil carbon	Numeric	%	5	3		0.003
Soil_temperature_regime	Soil_pedons	Temperature regime of a soil	Character		20	0		mesothermic
Mineral_family	Soil_pedons	NRCS mineral class	Character		20	0		Kaolinite
NUE_commercial	Crop_yield	% N of the applied commercial fertilizer used by the crop	Numeric	%	3	0	0-100	50
NUE_manure	Manure	% N of the manure available the crop	Numeric	%	3	0	0-100	80
NUE_greenmanure	Fallow_greenmanure	% N of the greenmanure crop available to the crop	Numeric	%	3	0	0-100	50
Region	Soil_pedons, Soil_fertility, Indicator_plant Crop_yield, Agroecosystem Fallow_greenmanure	Generalized continental geographic divisions	Character		15	0		Africa

Field Name	Table(s)	Definition	Type	Unit	Length	Precision	Valid Values	Example
Country	Soil_pedons, Soil_fertility Crop_yield, Fallow_greenmanure, Agroecosystem Prob_loc_order	Country	Character		20	0		Zaire
State	Soil_pedons	Providence or state	Character		30	0		Bas_Zaire
Agricultural_region	Crop_yield, Fallow_greenmanure, Soil_fertility, Agroecosystem	Agro-ecological region	Character		30			Savanna
Location	Soil_pedons, Prob_loc_order	Nearest town	Character		30	0		Kamina
Latitude	Soil_pedons	Latitude of location	Character	Degree, minute, second	7	0		24E1305
Longitude	Soil_pedons	Longitude of location	Character	Degree, minute, second	7	0		9S2508
Reference_number	Soil_pedons, Soil_fertility, Reference, Crop_critical, Soil_critical, Fallow_greenmanure, Indicator_plant, Plant_observation, Manure, Crop_yield, Probability	Reference number if information was derived from literature	Character		20	0	1-999	72

Field Name	Table(s)	Definition	Type	Unit	Length	Precision	Valid Values	Example
Crop	Crop, Crop_critical, Crop_yield, Soil_critical, Plant_observation, CV_parameter, PuptakeFactor	Crop (from the list of 12? Plants that we have identified for this system)	Character		20	0		Maize
N_percent	Crop_critical, Manure, Fertilizer, Soil_fertility	Nitrogen % (dry weight basis)	Numeric		6	2	0.05-99.00	1.25
P_percent	Crop_critical, Manure, Fertilizer	Phosphorus % (dry weight basis)	Numeric		6	2	0.05-99.00	0.09
K_percent	Crop_critical, Manure, Fertilizer	Potassium % (dry weight basis)	Numeric		6	2	0.05-99.00	1.00
Ca_percent	Crop_critical, Manure, Fertilizer	Calcium % (dry weight basis)	Numeric		6	2	0.05-99.00	2.00
Mg_percent	Crop_critical, Manure, Fertilizer	Magnesium % (dry weight basis)	Numeric		6	2	0.05-99.00	2.00
S_percent	Crop_critical, Fertilizer	Sulfur % (dry weight basis)	Numeric		6	2	0.05-99.00	2.00
Zn_ppm	Crop_critical	The critical level of zinc in a particular crop	Numeric	ppm	2	0	5-20	10
Fe_ppm	Crop_critical	The critical level of iron in a particular crop	Numeric	ppm	2	0	10-60	25
Mn_ppm	Crop_critical	The critical level of manganese in a particular crop	Numeric	ppm	2	0	10-30	20

Field Name	Table(s)	Definition	Type	Unit	Length	Precision	Valid Values	Example
Cu_ppm	Crop_critical	The critical level of copper in a particular crop	Numeric	ppm	2	0	1-5	2
B_ppm	Crop_critical	The critical level of boron in a particular crop	Numeric	ppm	2	0	1-15	4
Tissue_type	Crop_critical	The tissue type for the critical nutrient level	Character		50	0		Grain
Plant_development_stage	Crop_critical	The plant development stage for which the measure nutrient level is critical	Character		60	0		Harvest
Variety	Crop, Crop_yield, Crop_critical, Soil_critical	Crop variety or local name	Character		30	0		
Type	Crop_yield	Hybrid/Non-hybrid	Character		60	0		Non-Hybrid
Agroecosystem	Crop_yield, Agroecosystem	Rainfall regime	Character		15	0		Humid tropical
Map_code	Agroecosystem	Code used in map	Numeric		4	0		SA24
Scientific name	Crop	Crop Latin name	Character		60	0		Zea mays
Critical_element	Soil_critical, Prob_loc_order	The critical element that is being measured	Character		2	0		P
Soil_critical_level	Soil_critical	The content of an element below or above which the crop yield or performance is decreased	Numeric	Meq/100 g Ppm %	6	4		
AlSat_slope	Soil_critical	The slope of the relationship between Al_saturation and neutralization	Numeric		4	2		12.5
Description	Soil_critical	Description of the soil test procedure	Character		255	0		Standard Mehlich1

Field Name	Table(s)	Definition	Type	Unit	Length	Precision	Valid Values	Example
Diagnostic_variable	Probability	The diagnostic variable for which the probability of deficiency has been calculated	Character		35	0		Al
Deficiency	Prob_loc_order	The soil nutrient deficiency described by the diagnositc variable	Character		20	0		Low pH
CV	CV_parameter	Coefficients of variation of a parameter	Numeric	%	3	0	0-100	50
Parameter	CV_parameter	A factor used in uncertainty analysis	Numeric	%	3	0	0-100	**50**
Convert factor	PuptakeFactor	P conversion factor	Numeric		8	7	0-1	0.00234
Check_variable	Range_check	Variable in the model or data tables	Character		30	0		Crop_yield
Maximum_value	Range_check	Maximum that can exist for the numeric variable listed as the range check	Numeric	Different units	10	4		12000
Minimum_value	Range_check	Minimum that can exist for the numeric variable listed as the range check	Numeric	Different units	10	4		0
Fallow_type	Fallow_greenm anure	The type of fallow or green manure crop that precedes the crop of interest	Character		45	0		Mucuna
Length	Fallow_greenm anaure	The length that the fallow or green manure crop grows before it is killed	Numeric	Months	2	0	1-12	5

Field Name	Table(s)	Definition	Type	Unit	Length	Precision	Valid Values	Example
Management_practic e	Fallow_green manure	Description of the green manure or fallow management	Character	Kg/ha	255	0		Field was allowed to revert to a natural fallow of weeds and successional trees
N_contribution	Fallow_green manure	Potentially available plant available nitrogen contributed to the succeeding crop through nitrogen mineralization	Numeric	Kg/ha	3	0	1-500	50
P_contribution	Fallow_green manure	Amount of plant available phosphorus contributed to the succeeding crop	Numeric	Kg/ha	3	0	1-100	5
Lime_equivalent	Fallow_green manure, Manure	Reduction in soil lime requirement from organic inputs	Numeric	Kg/ha	5	0	500-40,000	1000
N_percent_vegetativ e	Crop_yield	Average %N in the stover of a particular crop at harvest (dry weight basis)	Numeric	%	5	2	0.10-10.00	2.52
N_percent_reproduc tive	Crop_yield	Average %N in the grain of a particular crop at harvest (dry weight basis)	Numeric	%	5	2	0.10-10.00	1.55
N_percent_total	Crop_yield Fallow_green manure	Average %N in the total biomass at harvest (dry weight basis)	Numeric	%	5	2	0.10-10.00	
P_percent_vegetativ e	Crop_yield	Average %P in the grain of a particular crop at harvest (dry weight basis)	Numeric	%	4	2	0.05-1.00	0.09

Field Name	Table(s)	Definition	Type	Unit	Length	Precision	Valid Values	Example
P_percent_reproductive	Crop_yield	Average %P in the stover of a particular crop at harvest (dry weight basis)	Numeric	%	4	2	0.05-1.00	0.09
P_Convert_factor	Crop_yield	P content of harvested portion of the plant and stover	Numeric	Kg/ha	3	0	5-150	30
Harvest index	Crop_yield	Grain yield divided by the stover yield	Numeric	%	2	0	5-80	75
Average_yield	Crop_yield	Average yield (harvestable portion) of given crop at a particular location or subregion	Numeric	Kg/ha	5	0	1-30,000	8000
Optimum_yield	Crop_yield	Maximum Average yield (harvestable portion) of given crop at a particular location or subregion (90% of maxiumum)	Numeric	Kg/ha	5	0	30,000	12000
Average_vegetative	Crop_yield	Average yield (vegetative portion) of given crop at a particular location or subregion	Numeric	Kg/ha	5	0	20,000	12000
Optimum_vegetative	Crop_yield	Maximum yield (vegetative portion) of given crop at a particular location or subregion (90% of maxiumum)	Numeric	Kg/ha	5	0	1-50,000	15,000

Field Name	Table(s)	Definition	Type	Unit	Length	Precision	Valid Values	Example
Average_total_dry matter	Crop_yield	Average total dry matter yield of the harvestable + vegetative portion of the crop (90% of maximum)	Numeric	Kg/ha	6	0	1-100,000	12,000
Optimum_total_dry matter	Crop_yield, Green_manure	Maximum total dry matter yield of the harvestable + vegetative portion of the crop	Numeric	Kg/ha	6	0	1-100,000	50,000
N_legume_contribution	Crop_yield	Estimated constribution of N to the succeeding crop	Numeric	Kg/ha	3	0	0-50	25
Rainfall	Crop_yield	Average annual rainfall	Numeric	Mm	4	0	1-9000	1500
Manure_type	Manure	Source of manure and/or compost applied	Character		20			Goat
Lime_equivalent	Manure, Fallow_greenmanure	The equivalent amount of lime derived from dry manure	Numeric	Kg/ha	5	0	500-50,000	10,000
Fertilizer	Fertilizer	Name of the commercial fertilizer material	Character		40	0		Urea
Fertilizer_type	Fertilizer	Type of fertilizer material: elemental or formula	Character		20	0		Formula
Fertilization	Prob_loc_order	P fertilization history	Character		5	0	1-1000	50
P_deficiency	Probability	Probability of P deficiency for corresponding diagnosis variable	Numeric		1	0	0-1	1
N_deficiency	Probability	Probability of N deficiency for corresponding diagnosis variable	Numeric			0	0-1	.7

Field Name	Table(s)	Definition	Type	Unit	Length	Precision	Valid Values	Example
A_deficiency	Probability	Probability of acidity problem for corresponding diagnosis variable	Numeric			0	0-1	.7
Ca_deficiency	Probability	Probability of Ca deficiency for corresponding diagnosis variable	Numeric			0	0-1	.7
Mg_deficiency	Probability	Probability of Mg deficiency for corresponding diagnosis variable	Numeric				0-1	.7
Variable1	Probability	Input variable	Character		40			Soil order
Plant_image_name	Crop_observation, Indicator_plant	Referral name to the picture	Character		20	0		CornN1
Crop_observation	Crop_observation		Character		40	0		
Indicator_plant	Indicator_plant	Plant indicative of a soil nutrient deficiency	Character		25	0		
Common_name	Indicator_plant	The common name of the plants that indicate nutrient deficiency	Character		30	0		
Nutrient_deficiency_N	Indicator_plant,	Nitrogen nutrient deficiency	Character		1	0		Y
Nutrient_deficiency_P	Indicator_plant,	Phosphorus nutrient deficiency	Character		1	0		blank
Nutrient_deficiency_L	Indicator_plant,	Lime nutrient deficiency	Character		1	0		y
Mn	Crop_observation	Manganese toxicity	Character		1	0		y
A		Acidity problem	Character		1	0		Y
P	Crop_observation	Phosphorus nutrient deficiency	Character		1	0		y

Field Name	Table(s)	Definition	Type	Unit	Length	Precision	Valid Values	Example
N	Crop_observation	Nitrogen nutrient deficiency	Character		1	0		y
Ca	Crop_observation	Calcium nutrient deficiency	Character		1	0		Y
Mg	Crop_observation	Magnesium nutrient deficiency	Character		1	0		Y
K	Crop_observation	Potassium nutrient deficiency	Character		1	0		Y
Stage	Crop_observation	Stage of growth for peach palm	Character		30	0		mature
Slide_source	Crop_observation	Slide author	Character		50	0		Potash and Phosphate Institute
Image_path	Crop_observation	The location of the image in the computer program	Character		50	0		Image_Lib\Nitrogen\
Yield_no_fert	Crop_yield	Yield without fertilizer applied	Numeric		10	1	0-15,000	835
Author(s)	Reference	Authors(s)	Character		100	0		Maini, S.B., P.Indira, R.C.Mandal,
Year	Reference	Year	Character		4	0		1977
Title	Reference	Title of the article	Character		250	0		Studies on maturity index in cassava.
Source	Reference	The remaining document information.	Character		250	0		J. of Root Crops 3(2):33-35. 1977. Studies on maturity index in cassava. J. of Root Crops 3(2):33-35.